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Review and synthesis

Use of meta-analysis in forest biodiversity research: key challenges and considerations

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ABSTRACT

Meta-analysis functions to increase the precision of empirical estimates and to broaden the scope of inference, making it a powerful tool for informing forest management and conservation actions around the world. Despite substantial advances in adapting meta-analytical techniques for use in ecological sciences from their foundations in medical and social sciences, forest biodiversity research still presents particular challenges to its application. These relate to the long timescales of successional stages, often precluding experimental designs, and the often-large spatial scales required to select random plots for sampling treatment factors of interest. Empirical studies measuring biodiversity responses to forest treatments vary widely in their quality with respect to the number of treatment replicates and the randomness of their allocation to treatment levels, with a high prevalence of pseudoreplicated designs. It has been suggested that meta-analysis can potentially offer a solution to the vast pseudoreplicated literature, because results from pseudoreplicated studies are formative collectively. Here we review the principal issues that arise when including differently designed studies in meta-analyses of forest biodiversity responses to forest management or disturbance, in addition to more general matters of appropriate question formulation and interpretation of synthetic findings. These concern the need for questions of practical value to forest management, appropriate effect size estimation and weighting of primary studies that differ in study design and quality. We recommend against using effect sizes that are standardized against within-study variance when pooling studies across different designs or across factors such as taxonomic group. We find a need for alternative weighting schemes to the conventional inverse of study variance, to account for variation between studies in their design quality as well as their observed precision. Finally, we recommend caution in interpreting results, particularly with regard to the possibility of systematic biases between reference and treatment stands.

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1. Introduction

The primary response of conservation biologists to the rapid global loss of forest quality and extent has been to establish systems of protected areas that regulate against biodiversity loss. Whilst the strict protection of old-growth forests will likely remain a conservation priority throughout the world, the potential for other types of forests to support biodiversity is gaining increasing recognition (Gibson et al., 2011; Putz et al., 2008). The importance of diversity is recognized in the global-scale Strategic Plan for Biodiversity, drawn up by the Convention on Biological Diversity and agreed upon by the governments of the world in Aichi, Japan 2011. Target 11 of the Strategic Plan states that by 2020, at least 17% of the areas of particular importance for biodiversity and ecosystem services are to be conserved through "ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures". Target 7 advocates the implementation of sustainable management strategies for production forests, and Target 15 calls for the restoration at least 15% of degraded areas through conservation and restoration activities. If we are to affect these targets for the forest ecosystems of the world, we need a sound empirical and synthetic understanding of the functioning and the relative biodiversity value of forests under varying management regimes and conservation designations. A synthetic understanding is best achieved through the systematic collation of empirical research and meta-analysis of primary studies, which can yield practical generalizations for guiding forest management and conservation.

The number of published meta-analyses in forest biodiversity research has increased greatly over the last decade, keeping pace with empirical research in this field (Fig. 1). The aims of such meta-analyses vary widely, from seeking accurate estimates of a critical parameter of interest, such as a point estimate of the overall shape of published species-productivity curves (Whittaker, 2010), to attributing variation in effect size to meaningful covariates across a broad pool of studies (Lajeunesse, 2010). The former aim is generally explored with random-effects models, and the latter is achieved with multiple subgroup analyses or mixed-effects meta-regressions (Gurevitch and Hedges, 1999). Meta-analyses yield generalizations of practical value for informing forest management practice when they summarize the magnitude and direction of effect sizes that measure impacts on biodiversity and they attribute variation in these effect sizes to meaningful covariates (Koricheva et al., 2013).

Meta-analysis was originally developed as a tool for the medical and social sciences, and was used extensively in these disciplines decades before its uptake in ecology (Lau et al., 2013). Systematic review and meta-analytical techniques have been adapted for use in ecology to account for higher empirical variability, necessitating different approaches to data synthesis (Pullin and Stewart, 2006), effect-size calculation (Lajeunesse, 2011), and meta-regression (Gurevitch et al., 2001). Despite substantial advances in the field, several authors (Halme et al., 2010; Koricheva and Gurevitch, 2014) have identified misuses of meta-analysis in ecology. Various guidelines exist to support ecological meta-analysis and interpretation (e.g. Harrison, 2011; Koricheva et al., 2013; Lortie et al., 2013), but the numerous recognized challenges have yet to be synthesised for applications to forest biodiversity. Meta-analyses of studies that measure biodiversity responses to forest management face particular issues to do with spatially configured plots measured over long timescales, and studies collated across diverse types and qualities of designs. Whilst these issues are not unique to forest biodiversity meta-analyses, they are particularly prevalent in this ecological discipline. For example, Gibson et al. (2011) meta-analyzed 2220 pairwise comparisons of biodiversity values in primary forests and disturbed forests that included studies with between 4 and 100 replicates and five different metrics of biodiversity. Chaudhary et al. (2016) meta-analyzed 1008 species richness differences between managed and unmanaged forests with between 2 and 336 replicates. Curran et al. (2014) meta-analyzed richness differences between old-growth and restored forest sites from 108 studies, with between 1 and 123 within-group replicates. The particular nature of the challenge is that replicates generally take the form of spatial plots, which make random and independent replication difficult at the forest scale. Moreover, the long timescales of successional stages often preclude experimental designs with precisely controlled treatment factors. The varying degrees of uncertainty among studies continues to impede our synthetic understanding of the ecological impacts of forest management and conservation interventions.

Here we focus on meta-analyses of biodiversity responses to forest management, disturbance, or conservation interventions. For each of the five principal stages of systematic review and meta-analysis, we identify key challenges for research on forest

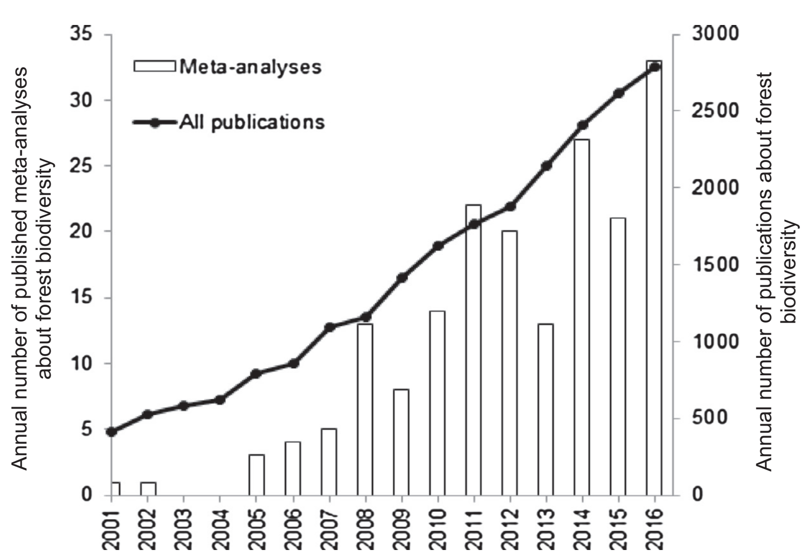

Fig. 1. Number of articles published per year in the ISI Web of Science containing the search terms 'forest' and 'biodiversity' (black lines) and also 'meta-analysis' (white bars).